Title: **Intelligent Monitoring System With High Temperature Distributed Fiberoptic Sensor For Power Plant Combustion Processes**

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Abstract

Objectives and Scope

The objective of the proposed work is to develop an intelligent distributed fiber optical sensor system for real-time monitoring of high temperature in a boiler furnace in power plants. Of particular interest is the estimation of spatial and temporal distributions of high temperatures within a boiler furnace, which will be essential in assessing and controlling the mechanisms that form and remove pollutants at the source, such as NOx. The basic approach in developing the proposed sensor system is three fold: (1) development of high temperature distributed fiber optical sensor capable of measuring temperatures greater than 2000 C degree with spatial resolution of less than 1 cm; (2) development of the boiler furnace monitoring model; and (3) development of an intelligent estimation theory for real-time monitoring of the 3D boiler temperature distribution.

Accomplishments To Date

Fiber optic sensor development:
1) Test the performance of high temperature fiber optic sensors based on harsh environment long period gratings. In the test, the fiber optic sensing head (i.e., a harsh environment long period grating) is inserted in a testing furnace. A broadband white light source is launched into the fiber via a standard fiber connector. The output end of the fiber is connected to a HP Optical Spectrum Analyzer (OSA). The spectrum response of the LPG is recorded at different temperatures. The spectral shift, as a function of temperature, clearly indicates that this unique harsh environment fiber optic sensor can sense the temperature change at high temperature.
2) Study the techniques to reduce the grating spectral bandwidth. One of the unique features of fiber grating based sensor is the distributed sensing capability. The narrower the spectral bandwidth of the grating, the more points can be sensed. We have investigated following techniques to reduce the grating spectral bandwidth: (a) reduce the diameter of the single crystal sapphire fiber by high temperature ($300\ ^{o}C$) HSO4 acid etching, (b) decrease the numerical aperture of sapphire fiber using the refractive index matched cladding layer, (c) control the number of modes propagated in multimode single crystal sapphire fiber.

Boiler furnace monitoring model development:
In the second year, the graduate student was trained with FLUENT to achieve the goals of this project with regard to multi-dimensional simulation. We are now working with a 2-D model of the Down Fired Combustor and a 3-D model of the Demonstration Boiler. Modeling the DFC has provided the graduate student the opportunity to become skilled using FLUENT, to leverage existing grids and extensive prior experimental work for comparison. Models obtained from 3-D modeling of the Demonstration Boiler were used to study relationships between temperature and NOx, as the multi-dimensionality of such systems are most comparable with real-life boiler systems. Studies show that in boiler systems with no swirl, the distributed temperature sensor may provide information sufficient to predict trends of NOx at the boiler exit. However, in more realistic cases, where the air at the boiler inlet is swirled (moderately), the chaotic characteristics of turbulent combustion are such that temperature alone is not sufficient to accurately dictate exit NOx information.

Intelligent estimation theory development:
In this research, we investigate a mathematical approach to extrapolation of the temperature distribution within a power plant boiler facility, using a combination of a modified neural network architecture and semigroup theory.

The 3D temperature data is furnished by the Penn State Energy Institute using FLUENT. Given a set of empirical data with no analytic expression, we first develop an analytic description and then extend that model along a single axis. The geometry of the furnace is cylindrical with the z-axis along the furnace axis, and with r going from one wall to the other wall. A simulation is performed on the configuration where there are 25 probes, each one providing 11 readings. Based upon an observation of the weight change sequence on the interval from 15 to 20, a semigroup-based rule for weight change is formulated and applied to the interval from 20 to 25, as a test. Extrapolation (to the region where no data were assumed) consists of the autonomous continuation of the rule for weight change, which was derived during the extrapolation test. The extrapolation is simulated in the region occupied by probes 25 to 30. This can be achieved by using the algebraic decomposition to obtain an analytic description of empirical data in a specific form, which involves the product of a coefficient vector and a basis set of vectors. Extrapolation consists of deriving an autonomous continuation of that particular weight change sequence which was responsible for the replication of the original coefficient vector trajectory; this continued weight change sequence, when inserted into the neural network, causes it to produce the continuation of the coefficient vector trajectory.

Future Work

❑ In the 3rd year of this project, we will (1) test the developed harsh environment sensor at higher temperatures (> 1000 ^{o}C) using higher temperature furnace (2) improve the developed sensor by achieving narrower spectral bandwidth and higher signal to noise ratio, and (3) apply to the real world applications.

❑ In the boiler furnace monitoring model development, subsequent applications of FLUENT to the Demonstration Boiler will focus on determining the means by which the output from the fiber optic sensor can be used to determine whether some control action is needed to reduce emissions (i.e., NOx).

❑ The concept will be also tested in other engineering problems where the systems have lack of an analytic description because of their complexity or lack of sufficient data because of their physical constraint.

Technical Publications

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3. Y. Yang, K. Chung, S. Yin, Z. Liu, and Q. Wang, "Analysis of volume holographic long period grating in photonic nanostructured fibers and waveguides," Optical Engineering, Vol. 43, pp.2003-2008 (2004).
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9. K. Shi, P. Li, S. Yin, and Z. Liu, "Chromatic confocal microscopy using supercontinuum light," Optical Express, Vol. 12, No. 10, pp. 2096-2101 (2004).
10. Kun-Wook Chung and Shizhuo Yin, "Analysis of a widely tunable long-period grating by use of an ultra thin cladding layer and higher-order cladding mode coupling," Optics Letters, Vol. 29, pp.812-814 (2004).
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12. K. Y. Lee, J. P. Velas, and B. H Kim, "Development of an Intelligent Monitoring System with High Temperature Distributed Fiberoptic Sensor for Fossil-Fuel Power Plants", *IEEE Power Engineering Society General Meeting*, pp. 1350-1355, Jun 6-10, 2004.

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